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Mineral Content Variation in Leaves, Stalks, and Seeds of Celery (*Apium graveolens* L.) Genotypes

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Abstract

Celery is an important nutritionally rich crop in the family *Apiaceae*. It is cultivated worldwide for food as well as for use in pharmaceutics. It is an excellent source of minerals, vitamins, and phytochemicals. Identification of superior genotypes with improved nutritional content is the requirement to develop cultivars for commercial cultivation. For mineral analysis of celery, an experiment was carried out taking 20 diverse genotypes. These genotypes were analysed for macro- and micronutrients which include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and sodium (Na). The study revealed high content of K (20.3–26.1 mg/g dry weight (DW)) and Zn (0.09–0.14 mg/g DW) in leaves while the stalks were rich in Ca (41.5–51.3 mg/g DW) and Na (5.2–8.0 mg/g DW). High contents of P (5.2–6.8 mg/g DW), Fe (0.41–0.56 mg/g DW), Cu (0.015–0.026 mg/g DW), and Mn (0.020–0.029 mg/g DW) were observed in seeds. Based on the mineral content, three genotypes, viz., PAU2, PAU4, and PAU7, were found to be superior in terms of mineral composition in leaves, stalks, and seeds. Cluster analysis divided the genotypes into two major groups. These genotypes can be used in crosses as they showed great potential for use in biofortification. This study opens newer avenues for future research, encouraging researchers to enhance the product quality and production efficiency of the leaves, stalks, and seeds valuable for human consumption.

Keywords Celery · Mineral content · Clustering analysis · Correlation · *Apiaceae*

Introduction

Celery (*Apium graveolens* L.), belonging to family *Apiaceae*, is an important medicinal plant grown for fresh herbs in different parts of the world. There are four known species of celery, namely, *A. graveolens*, *A. rapaceum*, *A. secalinum*, and *A. smallage*. Out of these, *A. graveolens* is mainly grown for leaf, stalk, and seed [1]. In the Middle East and Europe, the stalks and leaves of celery have been used as salad for thousands of years [2]. When the modern food industry came into existence, the celery seed oil gained great importance as it is mostly used as a flavouring agent in foods of Europe and the USA. Celery is available in the market as flakes, seeds, and seed oleoresin [3].

Being a medicinal crop, it is used for the treatment of cardiovascular disease, strengthening heart, and lowering blood pressure. The celery leaves, stalk, seeds, and microgreens contain important mineral nutrients such as calcium, iron, copper, potassium, magnesium, phosphorus, manganese, and sodium (Fig. 1). Celery boosts the immune system as it is a rich source of vitamin C and various antioxidants. The consumption of celery seeds lowers lipid levels in blood [4]. In India, celery is mainly used for juices and vegetables and as a flavouring agent in soups, meat, and pickles. It is also used in minor quantities in perfumes [5]. Celery has medicinal properties and can be prescribed as medication alone or in combination with other medicinal herbs as a supporting agent [6].

Globally, leaf celery production is concentrated in North America (predominantly USA) and Europe (France, Germany, the UK, Hungary, Italy, Belgium, and the

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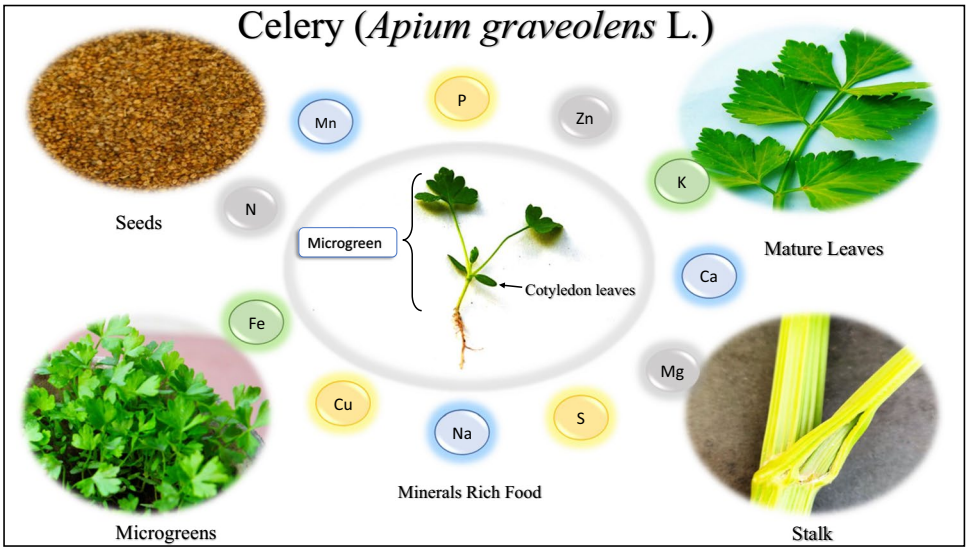

Fig. 1 Celery, an emerging food crop enriched with minerals

Netherlands). The acreage under celery in India is about 5000 ha, and 90% of the total production comes from Punjab state [7]. The annual production of celery in India is 40,000 tonnes, of which 29,250 tonnes is exported [8]. The average seed yield ranges from 1000 to 1500 kg/ha [3].

There is limited information available concerning the variability of mineral composition in various genotypes of celery along with breeding potential for mineral content improvement. Our study was designed to determine the mineral content in leaves, stalks, and seeds. An association of the mineral content among celery genotypes was also evaluated.

Material and Methods

Sample Collection

For mineral composition analysis in leaves, stalks, and seeds, 20 celery genotypes were sown in the nursery during *Rabi* season at Experimental Field Area, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab, India. The experiment was conducted in three replications. Leaves and stalks were harvested 60 days after transplanting and the seeds were collected at the time of harvesting. The leaves and stalk samples were rinsed under running tap water followed by washing with distilled water. Samples were dried in hot-air oven at 65° C for 72 h to achieve constant dry weight. The dried samples were crushed in a pestle and mortar up to fine powder form. The samples were stored in plastic bags for further estimation. From each replicate, 0.5 g of tissue sample was taken at the time of observations.

Chemicals

The chemicals used in the study were of analytical grade (AR). The standard solutions were prepared in double distilled water (DDW). Glass apparatus, prior to use in the laboratory experiments, was dipped in hydrochloric acid solution (2% v/v) for 24 h to avoid contamination. The glassware dipped in hydrochloric acid was rinsed with DDW before use. For elemental analysis, standard stock solutions having concentration of 1000mg/L were prepared and appropriately diluted with DDW for preparing working solutions.

Analytical Methods and Instrumentation

N content in leaves, stalks, and seeds was determined by the Kjeldahl method [9]. In this method, digestion of the samples was done in concentrated sulphuric acid, followed by distillation and titration. Concentration of P was determined by colorimetric method, while that of K, Na, and Ca was determined using Digital Flame Photometer (DFP). The content Fe, Zn, Mn, and Cu in the samples were analysed using Atomic Absorption Spectrophotometer (AAS) instrument calibrated with standard solution according to the official analytical method. For determination of P, K, Na, and Ca, samples were subjected to triple acid digestion (nitric acid:perchloric acid:sulphuric acid: 9:3:1) and for Fe, Zn, Mn, and Cu determination, samples were digested using Di-acid (nitric acid:perchloric acid: 3:1). Samples were digested till the clear solutions were obtained. After digestion, volume was made to 100 mL and stored in bottles for elemental analysis. In order to ensure accuracy, standard values were checked after every 20 samples analysed for validity of the calibration. The results were expressed as mg/g DW.

Statistical Analysis

The analysis of mineral composition was performed in three replications for each genotype. Concentration of mineral elements was evaluated on dry matter basis. The differences in mineral composition of the samples were tested using randomised block design (ANOVA) using R software and the mean comparison was evaluated using Tukey's honestly significant difference test with p value of 0.05 and n=3. To understand the similarities and dissimilarities among the twenty genotypes, hierarchical clustering analysis was performed using R software. Correlation among the minerals was determined using Pearson correlation coefficient.

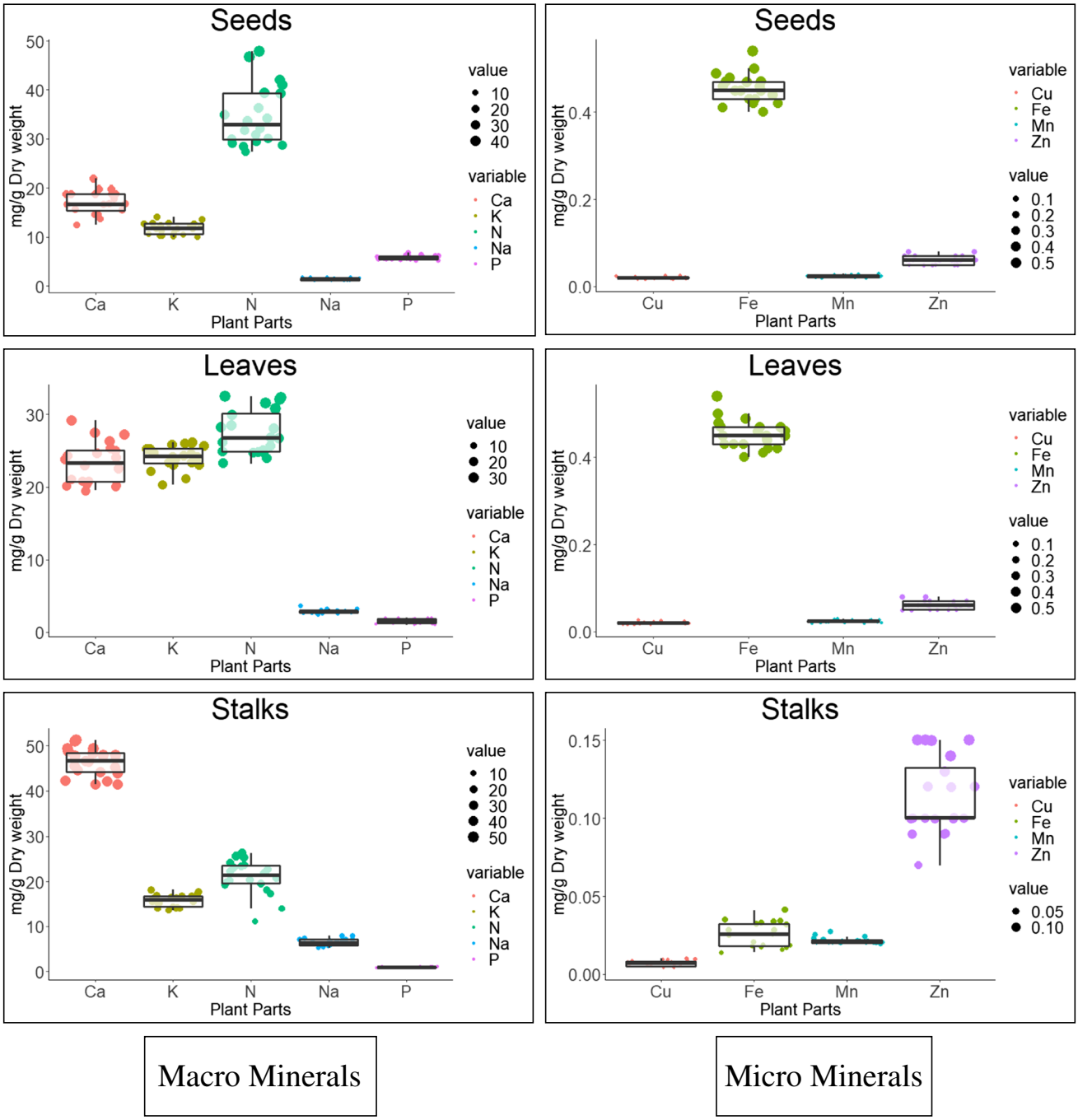

Fig. 2 Box plots for the macro- and micro-mineral content variation in leaves, stalks, and seeds of celery genotypes

Results and Discussion

Mineral Elements in Celery Leaves, Stalks, and Seeds

The distribution pattern of mineral contents in leaves, stalks, and seeds of 20 celery genotypes is shown in Fig. 2. Among the mineral elements, concentration of Ca was found higher in leaves, stalks, and seeds. The studied genotypes varied significantly in their element composition. Individual mineral content in seeds, leaves, and stalks of *A. graveolens* are shown in Tables 1, 2, and 3, respectively. The analysis of variance (ANOVA) showed significant differences among genotypes for element concentration (Table 4). The variability in genotypes poses significant importance in plant breeding programmes for selection of the most adequate lines.

N is an essential element for animals and humans as it is an important component of nucleic acids, amino acids, and proteins which are needed for proper functioning and body growth. Proteins play a vital role in various processes such as enzymes, in defence, blood clotting, fluid balance, and immune system response [10]. Significant differences were observed for N content between the genotypes. Genotypes PAU2 (26.3 mg/g DW), PAU18 (32.5 mg/g DW), and PAU15 (47.9 mg/g DW) showed higher N content in stalks, leaves, and seeds, respectively. According to the report by Consentino et al. [11], the N content showed higher value than P in celery leaves. The variation in concentration for N and P also depends upon the climatic conditions and genotypic variability [11].

P is an essential macro-element and acts as a dietary supplement in several foods. P deficiency (hypophosphatemia) in the body is mainly due to low dietary intake of phosphorus which causes anaemia, muscle weakness, and increased infection risk [12]. The P content in celery genotypes varied significantly in seeds but non-significant differences were observed in stalks and leaves, and the genotypes PAU3 (1.2 mg/g DW), PAU19 (2.0 mg/g DW), and PAU16 (6.8 mg/g DW) showed higher P content in stalks, leaves, and seeds, respectively. According to the USDA database, celery leaves contained 0.14mg/g of P. Similar results were also obtained by Malhotra [7] for P content (0.14 mg/g DW) in celery seed.

K assists in a range of essential functions of the body including normal water balance, heart rhythm, pH balance, muscle contraction, and blood pressure maintenance. It is made available to body through potassium-rich foods. K deficiency causes serious health issues but too much consumption causes long-term health problems also [13]. K content in celery genotypes showed significant differences

Table 1 Mineral content (mg/g DW) in seeds of 20 celery genotypes

Genotype	N	P	K	Na	Ca	Zn	Mn	Cu	Fe
PAU1	30.1^{fg}	6.0^{abcdef}	11.8^{de}	1.8^{a}	21.9^{a}	0.06^{a}	0.021^{ab}	0.023^{a}	0.46^{ef}
PAU2	39.4^{bcde}	5.4^{def}	12.2^{cd}	1.6^{a}	19.8^{b}	0.07^{a}	0.028^{ab}	0.020^{a}	0.48^{cd}
PAU3	34.9^{cdefg}	6.2^{abcd}	14.1^{a}	1.4^{a}	14.6^{fg}	0.06^{a}	0.022^{ab}	0.021^{a}	0.43^{hi}
PAU4	30.9^{fg}	5.7^{bcdef}	12.9^{bc}	1.2^{a}	16.7^{de}	0.06^{a}	0.029^{a}	0.024^{a}	0.49^{bc}
PAU6	36.3^{cdef}	5.7^{bcdef}	13.7^{ab}	1.8^{a}	18.8^{bc}	0.08^{a}	0.025^{ab}	0.020^{a}	0.50^{b}
PAU7	28.7^{fg}	5.4^{def}	10.9^{fgh}	1.0^{a}	16.7^{de}	0.05^{a}	0.027^{ab}	0.022^{a}	0.45^{fg}
PAU8	29.5^{fg}	5.2^{f}	11.7^{def}	1.8^{a}	18.8^{bc}	0.06^{a}	0.024^{ab}	0.017^{a}	0.54^{a}
PAU9	33.6^{defg}	6.1^{abcde}	10.2^{hi}	1.5^{a}	14.6^{fg}	0.05^{a}	0.022^{ab}	0.026^{a}	0.43^{hi}
PAU10	46.8^{ab}	5.3^{ef}	10.1^{hi}	1.8^{a}	18.8^{bc}	0.05^{a}	0.023^{ab}	0.020^{a}	0.42^{ij}
PAU11	41.1^{abcd}	5.9^{bcdef}	12.3^{cd}	1.4^{a}	15.6^{ef}	0.07^{a}	0.020^{b}	0.019^{a}	0.47^{de}
PAU12	29.1^{fg}	6.2^{abcd}	10.6^{ghi}	1.5^{a}	18.8^{bc}	0.05^{a}	0.027^{ab}	0.025^{a}	0.43^{hi}
PAU13	28.5^{fg}	5.4^{def}	11.1^{efg}	1.1^{a}	16.7^{de}	0.08^{a}	0.022^{ab}	0.019^{a}	0.47^{de}
PAU14	42.0^{abc}	5.7^{bcdef}	10.4^{ghi}	1.0^{a}	19.8^{b}	0.06^{a}	0.020^{b}	0.020^{a}	0.44^{gh}
PAU15	47.9^{a}	5.6^{bcdef}	12.8^{c}	1.6^{a}	18.8^{bc}	0.06^{a}	0.027^{ab}	0.021^{a}	0.45^{fg}
PAU16	30.0^{fg}	6.8^{a}	12.2^{cd}	1.5^{a}	15.6^{ef}	0.07^{a}	0.023^{ab}	0.019^{a}	0.47^{de}
PAU17	32.1^{efg}	5.4^{def}	12.9^{bc}	1.3^{a}	14.6^{fg}	0.05^{a}	0.024^{ab}	0.017^{a}	0.41^{jk}
PAU18	39.3^{bcde}	6.3^{abc}	11.7^{def}	1.4^{a}	16.7^{de}	0.06^{a}	0.024^{ab}	0.019^{a}	0.46^{ef}
PAU19	27.3^{g}	6.4^{ab}	12.7^{c}	1.2^{a}	17.8^{cd}	0.07^{a}	0.021^{ab}	0.021^{a}	0.45^{fg}
Punjab Celery 1	34.1^{cdefg}	5.5^{cdef}	10.2^{hi}	1.2^{a}	12.5^{h}	0.06^{a}	0.024^{ab}	0.015^{a}	0.42^{ij}
Ajmer Celery 1	31.7^{efg}	5.2^{f}	10.0^{i}	1.5^{a}	13.8^{g}	0.05^{a}	0.021^{ab}	0.016^{a}	0.40^{k}
Mean	**34.67**	**5.77**	**11.73**	**1.43**	**17.07**	**0.06**	**0.024**	**0.020**	**0.45**
CV	**7.63**	**4.62**	**2.43**	**22.31**	**2.11**	**49.54**	**12.02**	**22.54**	**7.90**

Data expressed as mean (n=3); different alphabets within the same column indicate significant difference across genotypes at $p \leq 0.05$. The results of one-way analysis of variance (ANOVA)

Table 2 Mineral content (mg/g DW) in leaves of 20 celery genotypes

Genotype	N	P	K	Na	Ca	Zn	Mn	Cu	Fe
PAU1	25.1^{a}	1.8^{a}	23.4^{fg}	2.9^{ab}	27.3^{b}	0.10^{a}	0.022^{a}	0.009^{abcd}	0.081^{defg}
PAU2	32.3^{a}	1.6^{a}	24.1^{def}	2.7^{ab}	29.2^{a}	0.10^{a}	0.015^{a}	0.010^{abcd}	0.092^{abc}
PAU3	31.6^{a}	2.0^{a}	26.0^{ab}	2.9^{ab}	26.3^{c}	0.13^{a}	0.020^{a}	0.007^{bcd}	0.081^{defg}
PAU4	24.7^{a}	1.1^{a}	20.3^{i}	2.7^{ab}	24.6^{def}	0.12^{a}	0.019^{a}	0.007^{bcd}	0.085^{abcdef}
PAU6	24.0^{a}	1.2^{a}	24.3^{de}	2.9^{ab}	27.5^{b}	0.12^{a}	0.022^{a}	0.006^{bcd}	0.089^{abcd}
PAU7	26.8^{a}	1.4^{a}	23.8^{efg}	3.6^{a}	25.0^{de}	0.09^{a}	0.013^{a}	0.010^{abcd}	0.075^{fg}
PAU8	23.2^{a}	1.0^{a}	23.4^{fg}	3.2^{ab}	20.2^{ij}	0.09^{a}	0.014^{a}	0.008^{abcd}	0.082^{cdefg}
PAU9	24.9^{a}	1.9^{a}	26.0^{ab}	3.2^{ab}	20.1^{ij}	0.12^{a}	0.015^{a}	0.006^{bcd}	0.084^{bcdefg}
PAU10	32.1^{a}	1.3^{a}	25.6^{ab}	2.6^{b}	20.8^{i}	0.09^{a}	0.022^{a}	0.005^{d}	0.084^{bcdefg}
PAU11	24.8^{a}	1.7^{a}	23.0^{gh}	2.8^{ab}	22.9^{gh}	0.14^{a}	0.016^{a}	0.009^{abcd}	0.088^{abcd}
PAU12	26.7^{a}	1.9^{a}	24.7^{cd}	2.6^{b}	21.0^{i}	0.10^{a}	0.022^{a}	0.014^{abcd}	0.074^{g}
PAU13	30.8^{a}	1.3^{a}	25.8^{ab}	3.1^{ab}	22.5^{h}	0.13^{a}	0.018^{a}	0.011^{abcd}	0.087^{abcde}
PAU14	28.5^{a}	1.4^{a}	25.2^{bc}	3.0^{ab}	24.3^{ef}	0.11^{a}	0.015^{a}	0.007^{bcd}	0.092^{abc}
PAU15	26.1^{a}	1.2^{a}	24.6^{cde}	2.7^{ab}	23.7^{fg}	0.13^{a}	0.020^{a}	0.013^{abcd}	0.081^{defg}
PAU16	28.1^{a}	1.8^{a}	21.1^{i}	2.5^{b}	25.3^{d}	0.10^{a}	0.016^{a}	0.016^{abc}	0.083^{bcdefg}
PAU17	24.7^{a}	1.3^{a}	25.2^{bc}	2.9^{ab}	24.0^{f}	0.12^{a}	0.020^{a}	0.017^{ab}	0.088^{abcd}
PAU18	32.5^{a}	1.9^{a}	23.0^{gh}	3.0^{ab}	20.4^{ij}	0.10^{a}	0.017^{a}	0.018^{a}	0.079^{defg}
PAU19	28.3^{a}	2.0^{a}	26.1^{a}	2.9^{ab}	20.8^{i}	0.13^{a}	0.018^{a}	0.009^{abcd}	0.077^{efg}
Punjab Celery 1	25.6^{a}	1.2^{a}	22.2^{h}	2.6^{b}	20.1^{ij}	0.09^{a}	0.012^{a}	0.013^{abcd}	0.093^{ab}
Ajmer Celery 1	29.9^{a}	1.3^{a}	24.1^{def}	2.8^{ab}	19.5^{j}	0.09^{a}	0.014^{a}	0.009^{abcd}	0.095^{a}
Mean	**27.54**	**1.52**	**24.1**	**2.88**	**23.28**	**0.11**	**0.018**	**0.010**	**0.080**
CV	**11.96**	**23.03**	**1.10**	**10.80**	**1.37**	**25.87**	**22.03**	**34.31**	**3.94**

Data expressed as mean (n=3); different alphabets within the same column indicate significant difference across genotypes at $p \leq 0.05$. The results of one-way analysis of variance (ANOVA)

in leaves, stalks, and seeds. The genotypes PAU6 (18.2 mg/g DW), PAU19 (26.1 mg/g DW), and PAU3 (14.1 mg/g DW) showed higher mean content of K in stalks, leaves, and seeds, respectively. The K content similar to these studies was reported by Golubkina et al. [14] in celery leaves. According to the USDA database, K content in celery seed is 14.0 mg/g DW showing similarity with our findings.

Na has an important role in controlling and regulating the blood volume at any instance. Hyponatremia disease is caused due to the deficiency of Na (less than 135 mEq/L). Majority of the sodium is consumed as part of diet. Na content showed significant differences among the genotypes, with PAU9 (8.0 mg/g DW), PAU7 (3.6 mg/g DW), and PAU1 (1.8 mg/g DW), having higher Na content in stalks, leaves, and seeds, respectively. Similar results were obtained by Malhotra [7] for Na content in seed. According to the USDA database, Na content in celery seed is 1.6 mg/g DW which is in accordance with our findings.

Ca is commonly related with the metabolism and formation of bones. It has been reported that 7% of the Ca comes from the vegetables such as broccoli, turnip leaves, watercress, celery, and kale. Ca helps in lowering the risk of high blood pressure, reduces cholesterol levels, and lowers the risk of colorectal adenomas (a type of non-cancerous tumour) [15]. This element showed higher content than other elements in celery genotypes and its higher concentration was found in stalks (41.5–51.3 mg/g DW) followed by leaves (19.5–29.2 mg/g DW) and seeds (12.5–21.9 mg/g DW). The genotypes PAU1 (21.9 mg/g DW), PAU2 (29.2 mg/g DW), and PAU7 (51.3 mg/g DW) showed higher Ca content in seeds, leaves, and stalks, respectively. Our findings for Ca content are in accordance as reported by Malhotra [7].

Zn performs functional, regulatory, and critical structural functions by interacting with enzymes and proteins in the body. Zn deficiency in our body is mainly due to consumption of only cereals and avoiding vegetables in diet. The Zn content in celery genotypes did not differ significantly and its content in genotypes ranged from 0.05 to 0.08 mg/g DW, 0.09 to 0.14 mg/g DW, and 0.07 to 0.15 mg/g DW in seeds, leaves, and stalks, respectively. The genotypes PAU6, PAU11, and PAU4 showed higher Zn content in seeds, leaves, and stalks, respectively. According to the USDA database, celery seeds contained 0.693 mg/g of Zn which shows similarity with our findings. Qureshi et al. [16] reported that celery leaves contained Zn with concentration of 0.012mg/g DW. Golubkina et al. [14] reported that celery leaves contained Zn in the range of 0.08 to 0.10 mg/g DW. Our findings for Zn content in mature leaves followed the same pattern as reported by Golubkina et al. [14].

Fe is the central atom involved in oxygen storage in muscle tissue having a significant role in energy-releasing processes from cellular respiration. Fe deficiency causes

Table 3 Mineral content (mg/g DW) in stalks of 20 celery genotypes

Genotype	N	P	K	Na	Ca	Zn	Mn	Cu	Fe
PAU1	20.5^{bcdef}	1.1^{a}	15.6^{efg}	7.2^{abcd}	48.3^{bc}	0.10^{a}	0.020^{a}	0.008^{a}	0.017^{de}
PAU2	26.3^{a}	0.9^{a}	14.1^{i}	6.9^{cde}	47.9^{cd}	0.09^{a}	0.021^{a}	0.009^{a}	0.018^{cde}
PAU3	25.6^{ab}	1.2^{a}	17.0^{bcd}	6.5^{def}	49.4^{b}	0.14^{a}	0.021^{a}	0.007^{a}	0.018^{cde}
PAU4	19.7^{cdef}	0.8^{a}	16.3^{def}	7.1^{bcde}	44.0^{i}	0.15^{a}	0.027^{a}	0.009^{a}	0.041^{a}
PAU6	19.3^{defg}	0.9^{a}	18.2^{a}	7.9^{ab}	45.6^{ghi}	0.10^{a}	0.020^{a}	0.008^{a}	0.035^{ab}
PAU7	22.3^{abcdef}	1.1^{a}	17.8^{ab}	6.0^{fgh}	51.3^{a}	0.12^{a}	0.024^{a}	0.009^{a}	0.034^{ab}
PAU8	18.1^{efg}	0.9^{a}	14.1^{i}	5.8^{fgh}	41.5^{j}	0.15^{a}	0.022^{a}	0.005^{a}	0.028^{bc}
PAU9	14.0^{gh}	1.0^{a}	15.3^{gh}	8.0^{a}	42.3^{j}	0.10^{a}	0.020^{a}	0.010^{a}	0.033^{ab}
PAU10	11.1^{h}	0.8^{a}	16.3^{def}	5.4^{h}	48.8^{bc}	0.12^{a}	0.021^{a}	0.006^{a}	0.018^{cde}
PAU11	17.3^{fg}	0.9^{a}	15.2^{gh}	5.2^{h}	46.7^{def}	0.10^{a}	0.019^{a}	0.008^{a}	0.017^{de}
PAU12	23.5^{abcde}	1.0^{a}	14.1^{i}	6.3^{efg}	49.4^{b}	0.09^{a}	0.023^{a}	0.007^{a}	0.032^{ab}
PAU13	24.2^{abcd}	0.9^{a}	16.5^{cde}	7.0^{cde}	46.5^{efg}	0.12^{a}	0.021^{a}	0.008^{a}	0.021^{cde}
PAU14	23.2^{abcde}	1.0^{a}	14.5^{hi}	5.8^{fgh}	41.5^{j}	0.10^{a}	0.021^{a}	0.010^{a}	0.014^{e}
PAU15	20.9^{abcdef}	0.9^{a}	15.5^{fg}	5.8^{fgh}	44.2^{i}	0.10^{a}	0.025^{a}	0.005^{a}	0.025^{bcd}
PAU16	22.8^{abcdef}	1.1^{a}	16.8^{cd}	6.3^{efg}	47.7^{cde}	0.09^{a}	0.020^{a}	0.005^{a}	0.016^{de}
PAU17	20.3^{bcdef}	0.8^{a}	17.4^{abc}	7.4^{abc}	51.0^{a}	0.07^{a}	0.022^{a}	0.005^{a}	0.032^{ab}
PAU18	25.3^{abc}	0.9^{a}	13.7^{i}	6.3^{efg}	44.6^{hi}	0.15^{a}	0.021^{a}	0.007^{a}	0.028^{bc}
PAU19	23.7^{abcde}	1.1^{a}	16.3^{def}	6.4^{defg}	47.9^{cd}	0.15^{a}	0.020^{a}	0.006^{a}	0.034^{ab}
Punjab Celery 1	19.9^{cdef}	0.7^{a}	14.4^{hi}	5.6^{gh}	45.2^{ghi}	0.10^{a}	0.021^{a}	0.004^{a}	0.019^{cde}
Ajmer Celery 1	21.9^{abcdef}	0.8^{a}	16.7^{cd}	7.2^{abcd}	42.1^{j}	0.13^{a}	0.020^{a}	0.004^{a}	0.026^{bcd}
Mean	**21.0**	**0.94**	**15.79**	**6.51**	**46.3**	**0.11**	**0.021**	**0.007**	**0.030**
CV	**8.66**	**30.39**	**1.90**	**4.10**	**0.93**	**26.62**	**14.66**	**43.76**	**13.39**

Data expressed as mean (n=3); different alphabets within the same column indicate significant difference across genotypes at $p \leq 0.05$. The results of one-way analysis of variance (ANOVA)

Table 4 Analysis of variance (ANOVA) for mineral content in seeds, leaves, and stalks

Plant part	Source of variation	d.f.	Mean Squares								
			N	P	K	Na	Ca	Zn	Mn	Cu	Fe
Seeds	Genotype	19	114.21^{***}	0.603^{***}	4.667^{***}	0.207^{*}	17.129^{***}	0.0002^{NS}	0.000002^{**}	0.00002^{NS}	0.0030000^{***}
	Replication	2	7.86^{NS}	0.006^{NS}	0.227^{NS}	0.043^{NS}	0.224^{NS}	0.0005^{NS}	0.000003^{NS}	0.00001^{NS}	0.0000010^{NS}
Leaves	Genotype	19	28.07^{**}	0.326^{**}	7.890^{***}	0.204^{*}	25.130^{***}	0.0008^{NS}	0.000031^{*}	0.00043^{***}	0.0000017^{***}
	Replication	2	6.02^{NS}	0.315^{NS}	0.049^{NS}	0.191^{NS}	0.011^{NS}	0.0005^{NS}	0.000009^{**}	0.00045^{NS}	0.0000005^{NS}
Stalks	Genotype	19	43.86^{***}	0.051^{NS}	5.412^{***}	1.94^{***}	28.080^{***}	0.0017^{*}	0.000001^{NS}	0.00001^{NS}	0.0000093^{***}
	Replication	2	0.54^{NS}	0.549^{**}	0.013^{NS}	0.408^{**}	0.121^{NS}	0.0004^{NS}	0.000001^{NS}	0.00003^{NS}	0.0000018^{NS}

*Significant at 5% probability level ($p < 0.05$); **Significant at 1% probability level ($p < 0.01$); ***Significant at 0.1%probability level ($p < 0.001$); ^{NS} non-significant differences

impairment of the brain and immune functions. In addition, its deficiency causes lowering of the amount of haemoglobin [17]. The dominant micronutrient in leaves, seeds, and stalks of celery was Fe. Significant differences were observed for Fe content in celery genotypes. The genotypes, PAU4 (0.041 mg/g DW), Ajmer Celery 1 (0.095 mg/g DW), and PAU8 (0.54mg/g DW), showed higher Fe content in stalks, leaves, and seeds, respectively. Our results are in accordance with those reported by Golubkina et al. [14].

Cu an essential microelement, helps in the normal metabolic activity but excess amounts can cause several problems such as increased frequency of infections and alterations in cholesterol metabolism [18]. Among the micronutrients, Cu content was lower in celery genotypes than other micronutrients. Significant difference was observed in leaves but non-significant differences were observed in seeds and stalks for Cu content. The genotype PAU9 showed higher Cu content in stalks (0.010 mg/g DW) and seed (0.026 mg/g DW) whereas, PAU 18 showed higher content in the leaves (0.018 mg/g DW).

Mn acts as an important cofactor for several catalytic reactions and metabolic activities such as carbohydrate metabolism and fatty acid synthesis [19]. The deficiency of Mn causes sterility, neurasthenia, asthma, and severe birth defects, and affects brain development [20]. The

Table 5 Mineral compositional value in celery leaves and seeds as reported in literature (USDA database)

Element	Leaves (mg/g DW)	Seeds (mg/g DW)
P	0.24	5.47
K	2.6	14.00
Na	0.80	1.60
Ca	0.40	17.70
Zn	0.0013	0.069
Fe	0.002	0.44
Cu	0.0035	0.0137
Mn	0.103	0.0757

genotypes showed significant differences for Mn content in seeds and leaves but non-significant difference was observed in stalks. The content of Mn was found higher in seeds (0.020–0.029 mg/g DW) followed by stalks (0.019–0.027 mg/g DW) and leaves (0.012–0.022 mg/g DW). The genotype PAU 4 showed higher content of Mn in seeds and stalk, whereas PAU 1 showed higher content in leaves.

The composition of minerals assayed in celery leaves and seeds as per USDA Food Data Central database is presented in Table 5.

Correlations Among Mineral Contents in Celery Leaves, Stalks, and Seeds

Correlations among mineral contents in celery leaves, stalks, and seeds were analysed by Pearson correlation coefficient. The results are presented in Table 6. Correlation study gives a general idea on how two traits under study are related to each other. The study on one character will give a perception on how other characters behave and their general trend of change can be forecasted beforehand. A significant and positive association was observed between Fe and Zn content in seeds; in the case of leaves, significant and negative association between Fe and P was observed; and in stalks, significant positive correlation was observed between Ca-K, Fe-Na, and Fe-Mn. Results from analysis revealed that high Fe content might be accompanied by high Na, Mn, and Zn content or vice versa.

Table 6 Correlation coefficients between mineral contents for seeds, leaves, and stalks in celery genotypes

	N	P	K	Na	Ca	Zn	Mn	Cu
P	−0.184[a]							
	0.327[b]							
	0.370[c]							
K	0.000	0.283						
	0.296	0.243						
	−0.095	0.181						
Na	0.252	−0.033	0.144					
	−0.144	−0.045	0.298					
	0.074	0.053	0.380					
Ca	0.200	−0.028	0.095	0.391				
	0.012	0.046	−0.127	−0.039				
	0.179	0.329	0.406	−0.048				
Zn	−0.035	0.189	.473*	0.008	0.19			
	−0.139	0.208	0.295	0.000	0.184			
	0.096	0.086	−0.036	−0.132	−0.289			
Mn	0.009	−0.202	0.200	0.051	0.150	−0.108		
	0.006	0.150	0.255	−0.335	0.278	0.326		
	0.059	−0.176	0.030	−0.078	0.018	0.186		
Cu	−0.093	0.403	0.053	0.034	0.369	−0.179	0.259	
	0.086	0.165	−0.268	−0.203	−0.110	−0.115	−0.060	
	0.037	0.334	−0.045	0.269	−0.022	−0.045	0.070	
Fe	−0.132	−0.010	0.401	0.271	0.441	.587**	0.266	0.036
	0.040	−.453*	−0.100	−0.263	0.084	−0.026	−0.336	−0.180
	−0.091	−0.112	0.276	.453*	−0.019	0.285	.499*	0.096

[a]Correlation coefficient for seeds; [b]correlation coefficient for leaves; [c]correlation coefficient for stalks

*Significant at 5% probability level ($p<0.05$); **significant at 1% probability level ($p<0.01$)

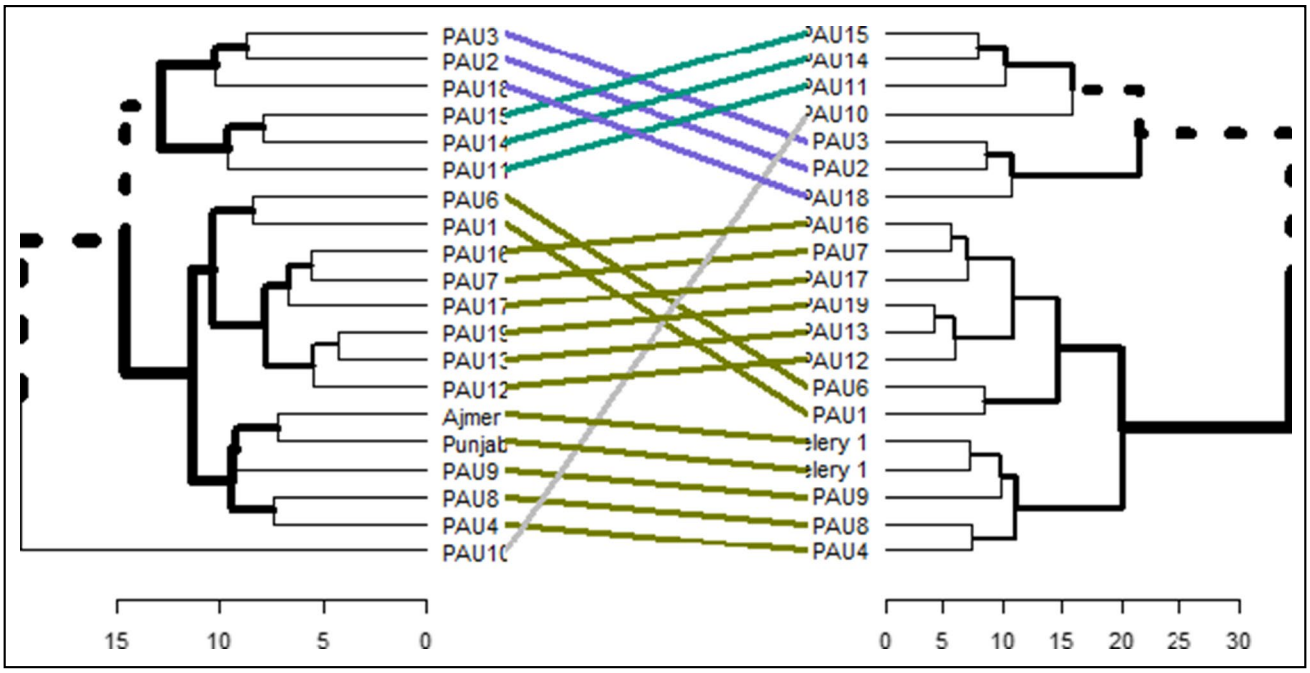

Fig. 3 Comparison of dendrograms for celery genotypes by means of hierarchical method using average distance between clusters (left) and Ward's minimum variance (right) using Euclidean distance as a measure of similarity

Cluster Analysis

Nine different minerals were employed to generate a Euclidean dissimilarity coefficient matrix followed by clustering using complete (left) and average (right) algorithms using R package. The two dendrograms thus obtained from the analysis are presented in Fig. 3. The analysis clustered the 20 genotypes into two major clusters. The first cluster consisted of 19 genotypes which further bifurcated into two groups consisting of six and thirteen genotypes while only one genotype (PAU10) formed the second cluster.

Potential Nutritional Contribution of Celery Leaves, Stalks, and Seeds

Daily nutrient requirements for an adult person and contribution of different plant parts of celery to nutrient requirements are presented in Table 7. According to our study, Ca was the major contributor among the macronutrients while in micronutrients Fe was found higher. Zn and Fe deficiencies, together with iodine and vitamin A deficiency, are globally the chief causes of malnutrition [21]. Inclusion of leaves and stalks of celery in salad and seeds used for garnishing and top dressing would contribute substantial amount of daily body requirement. Intake of appropriate amount of these herbs could compensate the requirement of body and would aid in our fight against malnutrition and pave the way towards nutritional security.

Table 7 Daily nutrient requirements for an adult person (mg/day) and contribution (mg/g DW) of different plant parts of celery to nutrient requirements

Element	Recommended (mg/day)	Seeds (mg/g DW)	Leaves (mg/g DW)	Stalks (mg/g DW)
P	700[a]	5.2–6.8	1.0–2.0	0.7–1.1
K	3100	10.0–14.1	20.3–26.1	13.7–18.2
Na	1300–1500	1.0–1.8	2.5–3.6	5.2–8.0
Ca	900–1000	12.5–21.9	19.5–29.2	41.5–51.3
Zn	7.0–9.5	0.05–0.08	0.09–0.14	0.07–0.15
Fe	9–18	0.41–0.56	0.074–0.095	0.014–0.041
Cu	1.1	0.015–0.026	0.005–0.018	0.004–0.010
Mn	1.8–2.3	0.020–0.029	0.012–0.022	0.019–0.025

[a]Cuervo et al.[22]

Conclusion

The mineral estimation in leaves, stalks, and seeds of studied celery genotypes provides a quantification for their macro- and micro-element concentration. This study shows that celery leaves, stalks, and seeds are good sources of macro-elements (e.g., K and Ca) and micro-elements (e.g., Fe and Zn) for a balanced human diet that would fulfil a significant portion of daily nutrient requirement. From the present study, the genotypes PAU2, PAU4, and PAU7 are favoured over the other genotypes from mineral content point of view. A crop with good nutritional value is highly desirable. The study revealed high content of K and Zn in leaves while the stalks were rich in Ca and Na. High content of P, Fe, Cu, and Mn was observed in seeds. We suggest the utilisation of genotypes, namely PAU2, PAU4, and PAU7, in subsequent breeding programmes to simultaneously improve yield and nutritional quality of the crop. Celery breeding is a new avenue for future research, encouraging researchers to enhance the product quality and production efficiency of the leaves, stalks, and seeds valuable for human beings. Further enhancement of available nutrients by biofortification through various breeding, biotechnological, and agronomic interventions at field level would make celery a nutrient-rich and medicinal wonder crop.

Author Contribution Mandeep Singh, Usha Nara, and Manjeet Kaur Sangha conceived and designed the paper; Mandeep Singh and Usha Nara collected and analysed the literature and wrote the manuscript; Neeraj Rani provided the lab facility; Mandeep Singh and Kirandeep Kaur finalised the figures and tables; Dharminder Pathak, Usha Nara, and Manjeet Kaur Sangha reviewed and edited the manuscript. Mandeep Singh did the statistical analysis. All the authors read and approved the manuscript.

Data Availability Data sharing is not applicable to this article as no datasets were generated or analysed during the current study

Declarations

Conflict of Interest The authors declare no competing interests.

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